Chapter 2
Ambient Assisted Living: Systematic Review

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2.1 Introduction

The active ageing paradigm aims to contribute to the expectation of a healthy, autonomous and independent life with quality (World Health Organization 2002). The technological solutions might have a key role in the promotion of human functioning and in the mitigation of disabilities, particularly those resulting from the natural ageing process. This perspective is evident in the development of Ambient Assisted Living (AAL) solutions (Martins et al. 2017).

AAL, like AmI, uses the integration of computational devices in the persons' natural environments (e.g. clothes or furniture). These computational devices allow the adaptation of the physical environment to the needs of the users (Queirós et al. 2013a; Bell and Dourish 2007), through the capture of data representing the state of the surrounding environments. AAL solutions must be able to process available sensory information, which will serve as a basis for decision-making processes to anticipate reactions to possible events or to act on the environments to modify their state (Cook and Das 2007).

The acceptance of AAL solutions is closely related to the quality of the available solutions, namely, in terms of intelligent functions for the users' interaction.

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Therefore, the development of AAL solutions must consider the needs of the users in order to assist them in their daily activities, making their lives more comfortable and helping them to participate in all areas of life, as well as to be accepted and included (Queirós et al. 2013a).

In this context, it is relevant to know the recent developments in AAL and to discuss its future trends and challenges. Therefore, the authors systematically review and classify the AAL literature to establish the current position regarding the AAL services being developed, users' involvement and evaluation methods.

2.2 Methods

The systematic review and classification of the AAL literature was informed by the following research questions:

- RQ1: What AAL solutions and respective application domain are being developed?
- RQ2: How are AAL solutions being evaluated?

This systematic review followed the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al. 2009).

2.2.1 Data Sources and Searches

Studies were sought using general databases (i.e. Scopus, Web of Science and Academic Search Complete), a healthcare database (i.e. PubMed) and computer, information science and electrical engineering databases (i.e. IEEE Xplore).

The database queries were prepared to include all the articles where any of the keywords mentioned in Table 2.1 were presented in the title or abstract, according

Table 2.1 Search terms used for database queries

	Search terms	Type
1	"Technology-based" OR "information technology" OR "information and communication" OR "internet-based" OR "web-based" OR "online" OR "smartphones" OR "mobile apps" OR "mobile phone" OR "monitoring devices"	General terms
2	AAL OR "ambient assisted living" OR "ambient assisted technology" OR "ambient assistive technology" OR "ambient intelligence" OR AmI OR "smart home" OR "intelligent home"	General terms
3	"Independent living" OR "assisted living facilities" OR "assisted living facility"	MeSH terms
4	Aged OR aging OR elderly OR senior OR old	General terms
5	Aged OR aging	MeSH terms

to the following Boolean combination 1 AND (2 OR 3) AND (4 OR 5). Whenever the databases allowed, MeSH terms were used.

The search was performed on February of 2018 and included all references published since January 1, 2007 till December 31, 2017. The starting date was established as 2007, because it was in this year that the European Commission launched the Ambient Assisted Living Joint Programme (European Union 2007).

2.2.2 Inclusion and Exclusion Criteria

In terms of inclusion criteria, the included articles should report AAL solutions that might be used to support older adults.

Moreover, the exclusion criteria were (1) articles not published in English, (2) articles reporting editorials or prefaces, (3) articles reporting systematic reviews, (4) articles reporting surveys and (5) articles that are not relevant for the objectives of the study reported in this chapter.

2.2.3 Review Selection

After the removal of duplicates and articles not published in English, the authors independently reviewed all titles for relevance and assessed the abstracts of the retrieved articles against the inclusion and exclusion criteria. Any disagreement between the authors was discussed and resolved by consensus.

2.2.4 Data Extraction and Analysis

For every one of the included articles, the following information was registered in a data sheet prepared by the authors:

- Scope of the article – aim of the AAL solutions;
- Context – specific context where AAL solutions are planned to be used (e.g. residential environment, institutional environment or outdoor);
- Type of user – identification of the preferable type of users (e.g. older adults, patients or caregivers);
- Type of technology – description of the main technological characteristic of the AAL solutions (e.g. hardware component, software component or architecture);
- Type of services – practical AAL systems applied in a specified context and with a well-defined aim (e.g. monitoring systems, falls detection systems or medication management);

- Evaluation methods – description of the assessment of the AAL solutions (e.g. conceptual validation, prototype or pilot).

Afterwards, the collected data was analysed to answer the previous referred research questions.

2.3 Results

Figure 2.1 presents the PRISMA flowchart of the systematic review reported in the present chapter.

A total of 1342 articles were retrieved from the initial searches on Scopus (525), Web of Science (171 articles), Search Academic Complete (334 articles), PubMed (155 articles) and IEEE Explorer (157 articles). The initial screening yielded 642 articles by removing the duplicates (648 articles) or the articles without abstracts (53 articles). A total of 374 articles were excluded based on the review of the titles and abstract. From these, 11 articles reported editorials or prefaces, 26 were systematic reviews, 81 were surveys and 256 were out of scope. Consequently, 267 articles were included in this systematic review.

The evolution through the reviewed 10 years period is presented in Fig. 2.2. It is clear that in the increasing number of AAL solution over the years, although between 2015 and 2017, there was a slight decrease.

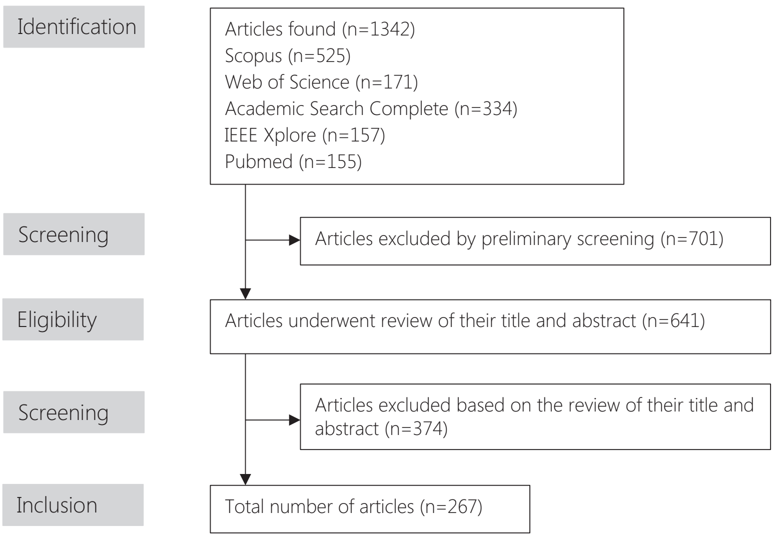


Fig. 2.1 PRISMA flowchart

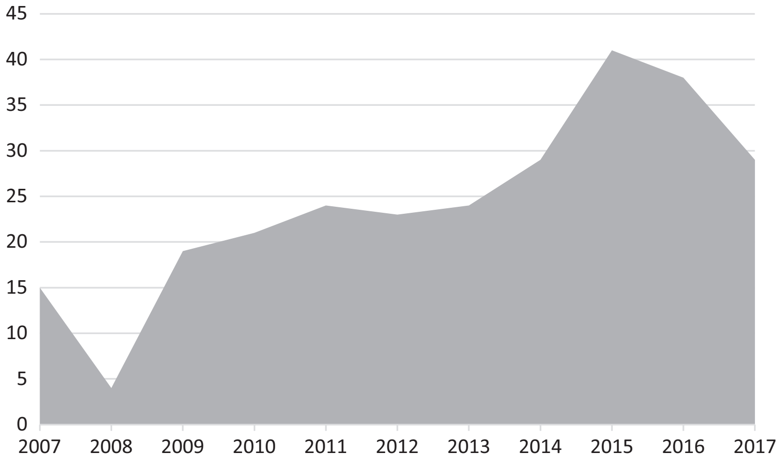


Fig. 2.2 Evolution of the number of articles per year between 2007 and 2017

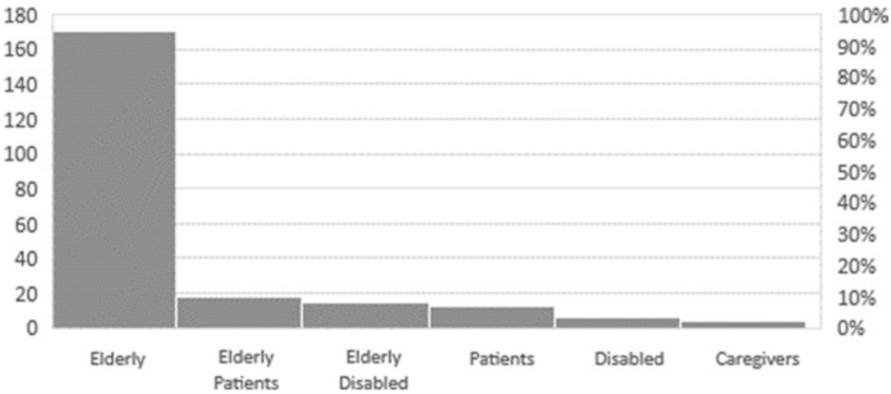


Fig. 2.3 Users of AAL solutions

In what concerns the target users (Fig. 2.3), most of the retrieved articles had older adults as target users (76%), considering that the articles referred not only older adults (170) but also older adults and patients (18) or disabled citizens (15). Only four articles reported caregivers or general citizens as target users. Finally, 19 articles developed AAL solutions for patients or disabled citizens, and 41 did not specify the preferable type of users.

The context where AAL solutions are planned to be applied is presented in Fig. 2.4. A significant percentage (i.e. 66%) referred residential environment as the context of use, just 1% of the articles indicated institutional or outdoor context of use, and 33% of the articles did not refer where the AAL solution are planned to be used, since most of them were related to the development of specific components of hardware or software which could be integrated in other AAL solutions.

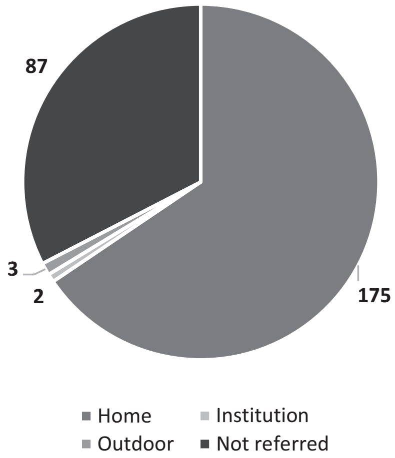
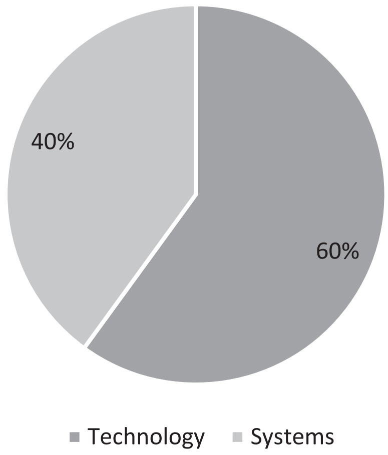


Fig. 2.4 Types of contexts where AAL solutions are planned to be used

From the analysis of the retrieved articles, they were classified as technology or systems. Technology articles refer to the description of an architecture or a component, such as a specific algorithm. A system is a practical AAL system applied in a specified context and with a well-defined aim. Near 60% of the articles were classified as technology (Ahmad et al. 2016a, b; Alemán et al. 2015a, 2016; Alexander et al. 2011; Amala Rani et al. 2015; Anastasiou 2012; Andò et al. 2014; Anguita et al. 2012; Anido et al. 2013; Arcelus et al. 2007; Armstrong et al. 2010; Atayero et al. 2016; Bae and Kim 2011; Baldewijns et al. 2016; Bamidis et al. 2010; Batool et al. 2014; Bisio et al. 2015; Blasco et al. 2014; Boers 2009; Bonino et al. 2012; Boucha et al. 2017; Bravo et al. 2012; Brestovac et al. 2014; Brulin et al. 2012; Burns et al. 2012; Carneiro et al. 2010; Chang et al. 2014; Chen 2007; Chiang and Liang 2015; Cleland et al. 2014; Conejar et al. 2016; Costa et al. 2017; 2010; Culmone et al. 2014; Cunha 2015; Davis et al. 2016; Dayangac and Hirtz 2014; de Backere et al. 2017; De Ruyter and Pelgrim 2007; De Santis et al. 2015; Demiris and Thompson 2011; Dengler et al. 2007; Dersingh 2014; Doukas and Maglogiannis 2011; Eichelberg et al. 2010; Evchina and Martinez Lastra 2016; Fan et al. 2015; Fergus et al. 2011; Fernández et al. 2009; Fernandez-Carmona and Bellotto 2016; Fleury et al. 2010; Fong et al. 2012; Freitas et al. 2014; Gappa et al. 2012; García et al. 2009; García-Rodríguez et al. 2015; Gatton and Lee 2010; Gil et al. 2007; Gjoreski et al. 2014; Havlík et al. 2012; He and Zeadally 2015; He 2016; Hegarty et al. 2009; 2010; Hein et al. 2010; Hong and Nugent 2009; Hui-Kyung and In-Cheol 2011; Islam 2011; Islam et al. 2009; Istepanian et al. 2011; Ivanov et al. 2015; Jara et al. 2009; Jenko et al. 2007a, b; Kaenampornpan et al. 2011; Kantawong 2016; Katzouris et al. 2013; Kelly et al. 2017; Kelly et al. 2009; Kentta et al. 2007; Kieffer et al. 2009; Kim et al. 2010; Konstantinidis et al. 2015; Koshmak et al. 2013; Kunnappilly et al. 2016; 2017; Lampoltshammer et al. 2014; Lankri et al. 2009; Lenca et al. 2016; Leone et al. 2011; Locatelli et al. 2017; Lopez Mejia et al. 2016; Luca et al. 2013; Madias 2016; Magherini et al. 2013; Maglogiannis et al. 2016; Marschollek et al. 2007; Miranda et al. 2016; Mitabe and Shinomiya 2017; Moraru et al. 2017; Moreno et al. 2013; Morgavi et al. 2007; Moumtzi et al. 2009; Nef et al. 2014; Nilas 2011; Nisar et al. 2016; Nuovo et al. 2014; Oberzaucher et al. 2009; Otoom and Alzubaidi 2017; Ou et al. 2013; Ouedrago et al. 2017; Palumbo et al. 2014; Pardo et al. 2015; Persson et al. 2013; Pioggia et al. 2009; Pistorio et al. 2017; Pontes et al. 2017; Porambage et al. 2015; Qadeer et al. 2009; Quer and Danieletto 2015; Quero et al. 2007; Quintas et al. 2013; Ramlee et al. 2012; Reis et al. 2016; Ribeiro et al. 2015; Saidinejad et al. 2015; Saives and Faraut 2014; Salatino et al. 2016; Schlebusch 2011; Schneider et al. 2017; Shamsi et al. 2011; Sheahen and Skubic 2015; Sili et al. 2013; Sili et al. 2014; Sommaruga et al. 2011; Sorvala et al. 2012; Spanoudakis et al. 2010; Su 2015; Su and Chiang 2013; Su and Shih 2011; Sucerquia et al. 2017; Symonds et al. 2007; Tan et al. 2013; Terroso et al. 2013; Tran 2015; Alam 2017; Unluturk and Kurtel 2012; Vacher et al. 2014; Valero et al. 2013; Vanus et al. 2017; Venkatesh et al. 2011; Viet et al. 2012; 2013; Vineeth et al. 2017; Vinjumur et al. 2010; Xiao 2013; Yamazaki 2012; Yang et al. 2016; Yao et al. 2016a; b; Yu et al. 2012; Yuan and Bureau 2016; Yuchae 2017; Zarri 2013; Zeng 2008; Zhou 2010; Zolfaghari et al. 2016; Zou et al. 2008).

Moreover, 40% were classified as systems (Alexander et al. 2011; Bamidis et al. 2010; Chiang and Liang 2015; Freitas et al. 2014; Kentta et al. 2007; Koshmak et al. 2013; Ribeiro et al. 2015; Sili et al. 2014; Terroso et al. 2013; Agoulmine et al. 2011; Ahanathapillai et al. 2015; Alam et al. 2016; Alemán et al. 2015b; Ando et al. 2015; Angelo et al. 2010; Austin et al. 2016; Backere et al. 2017; Barham et al. 2015; Basili et al. 2016; Boulos et al. 2011; Cao et al. 2012; Carús et al. 2014; Chang et al. 2016; Ciampolini et al. 2016; Coronato et al. 2010; Costa et al. 2014; Damaševičius et al. 2016; Danilovich et al. 2017; De Maso-Gentile et al. 2015; Deen 2015; Dohr et al. 2010; Doyle and Walsh 2015; Eichelberg et al. 2014; Ejupi et al. 2015; Fahim et al. 2012; Ferreira and Ambrósio 2012; Figueiredo et al. 2016; Fiorini et al. 2017; Foroughi et al. 2008; Fratu et al. 2015; Göllner et al. 2011; Govercin et al. 2016; Gschwind et al. 2015a; b; Helmy and Helmy 2015; Hervas et al. 2013; Hidalgo et al. 2011; Hill et al. 2015; Hine et al. 2012; Holthe and Walderhaug 2010; Iglesias et al. 2009a; b; Jeon et al. 2017; Juang and Wu 2015; Junnila et al. 2010; Kaluza et al. 2010; Kaye et al. 2008; Kiselev et al. 2015; Krishnan and Cook 2014; Kue et al. 2015; Kuhn et al. 2009; Lee et al. 2011; 2013; 2015; Li et al. 2009; 2015; Losardo et al. 2011; 2014; Lotfi et al. 2017; Magar et al. 2017; Maglogiannis 2014; Martin et al. 2013; McCrindle et al. 2011; Miori and Russo 2017; Mitseva et al. 2009; Mokhtari and Feki 2007; Nakagawa et al. 2016; Niemela et al. 2007; Norgall and Wichert 2013; Núñez-Naveira et al. 2016; Ogonowski et al. 2016; Passas et al. 2012; Payyanadan et al. 2017; Pensas et al. 2013; Pierleoni et al. 2015; Prescher et al. 2012; Preuss and Legal 2017; Rakhman et al. 2014; Richter et al. 2015; Rosas et al. 2014; Schaad et al. 2016; Schenk et al. 2011; Seewald et al. 2010; Shen et al. 2013; Siegel et al. 2014; Silveira et al. 2013; Spinsante 2017; Stucki and Urwyler 2014; Sun et al. 2009; Suryadevara and Mukhopadhyay 2014; 2015; Ueda et al. 2015; Ullah et al. 2012; Wolfgang Inninger and Nicole Wagner 2012; Zambanini et al. 2010; Žele et al. 2017; Zhou et al. 2016) (Fig. 2.5). Nine articles referring to different types of developments were classified both as technology and systems, considering that they reported a technological

Fig. 2.5 Distribution of articles classified as technology and systems



component, as well as the system integrating that component. For example, Zhou et al. (2010) developed a personal diabetes monitoring system which integrates wearable sensors and 3G mobile phones.Several articles refer to the development of architectures (i.e. the rationale for the integration of different component and services). An example is the study of Quero et al. (2007) that presents the MIMOSA architecture and the respective development platform to create applications, or the article of J. Yuchae (2017) that proposes a hybrid inspection service middleware for monitoring older adults. Examples of specific components are a RFID prototype (Symonds et al. 2007) or a low-cost wireless sensor network (Nilas 2011). Other articles considered the development of specific algorithms to process information (e.g. ontologies to support the management of networks of sensors (Culmone et al. 2014), methods to capture and process data streams (Maglogiannis et al. 2016) or signal processing and machine learning algorithms to detect physiological symptoms and infer macro-level activities (Alam 2017)). There were also articles that reported more complex developments (e.g. Chang et al. (2014) reported a motion-sensing carpet for tele-monitoring mobility level, indoor locations and fall events and presented multiple interactive applications based on this motion-sensing carpet, or Vacher et al. (2014) that developed a voice command integrated in a smart home).

Some articles refer developments related to the interaction with AAL solutions. For instance, Férnandez et al. (2009) presented a method and an implementation of an interface with smart homes, based on natural language, or Hegarty et al. (2010) presented a cooperative interface communication coupled with context awareness to facilitate the optimisation and customisation of displays. Few of the reported solutions are based on Internet Protocol TV (IPTV). Moreover, the concerns with the interoperability of different components are scarce.

The different types of AAL systems found in this review are presented in Fig. 2.6. A description of the objective of the articles classified as systems can be found in Annex I.

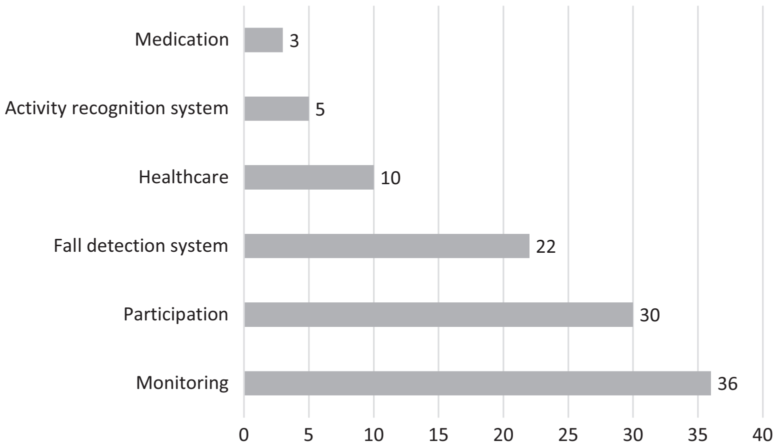


Fig. 2.6 Distribution of articles considering the type of systems

Only three articles (Fiorini et al. 2017; Lee et al. 2011; Spinsante 2017) were related to medication management. Lee et al. (2011) developed a system that integrates RFID-based medication management. Other example is the work of Fiorini et al. (2017) that presents a hybrid robot cloud approach to develop a service model for personalized medical support.

According to our analysis, the reported solutions to perform activity recognition (Damaševičius et al. 2016; Krishnan and Cook 2014; Nakagawa et al. 2016; Ueda et al. 2015; Zhou et al. 2016) (i.e. systems able to detect different activities) were classified as systems. For instance, finger-worn devices (Zhou et al. 2016), wearable devices (Nakagawa et al. 2016) or power metres attached to appliances or positioning sensor (Ueda et al. 2015) are able to recognize different daily living activities, without compromising the privacy of the users.

As expected, most of articles (i.e. 36 articles) classified as systems are related to home monitoring of different physiological parameters or activities of older adults, using different methods (Alexander et al. 2011; Zhou 2010; Agoulmine et al. 2011; Alam et al. 2016; Alemán et al. 2015b; Angelo et al. 2010; Austin et al. 2016; Boulos et al. 2011; Chang et al. 2016; Ciampolini et al. 2016; Coronato et al. 2010; Deen 2015; Dohr et al. 2010; Fahim et al. 2012; Ferreira and Ambrósio 2012; Fratu et al. 2015; Hine et al. 2012; Kaluza et al. 2010; Kaye et al. 2008; Li et al. 2015; Losardo et al. 2011; Losardo et al. 2014; Lotfi et al. 2017; Niemela et al. 2007; Richter et al. 2015; Stucki and Urwyler 2014; Suryadevara and Mukhopadhyay 2014; Suryadevara and Mukhopadhyay 2015; Žele et al. 2017). For example, Kaluza et al. (2010) proposed a system that is composed of seven groups of agents providing flexible monitoring of older adults in their environments, reconstructing positions and postures aiming to create physical awareness of the older adults, to react to critical situations, to call for help in the case of an emergency and to issue warnings if unusual behaviours are detected.

Home monitoring of health conditions together with the possibility of interaction with healthcare providers are functions presented in the AAL systems being reported. For instance, the eCAALYX (Boulos et al. 2011) android smartphone application receives inputs from a patient-wearable smart garment with wireless health sensors and from a global positioning system (GPS) location sensor in the smartphone and communicates over the Internet with a remote server accessible by healthcare providers. Also, Ciampolini et al. (2016) argued about a strategy for indirect monitoring of health conditions, requiring less participating effort of older adults. They propose the deployment of a highly heterogeneous sensing network in the older adults living environments, including clinical devices (e.g. measuring blood pressure, body weight, blood sugar or oxygen concentrations), environmental devices (e.g. room presence, bed/chair occupancy, toilet usage, fridge or pantry access) and wearable devices (e.g. accounting for physical activity evaluation, fall detection or carrying identification information).

Losardo et al. (2014) evaluate, for several months in a real context, a system that includes three sensors of presence located in the bathroom, the hallway and the kitchen: a bed-occupancy sensor, a sofa-occupancy sensor and a door sensor on the main door. All sensors were wirelessly connected with ZigBee technology, and the network activity was logged in a database. The system aims at helping relatives and caregivers to identify suggestive alterations in health status of older adults as early as possible. Also, Suryadevara and Mukhopadhyay (2015) monitor important daily activities through the observation of everyday object usages to inform caregivers about the activities of the patients.

In what concern to systems to improve the communication between the patients and caregivers, ten articles were identified (Ribeiro et al. 2015; Figueiredo et al. 2016; Govercin et al. 2016; Hervas et al. 2013; Hidalgo et al. 2011; Hill et al. 2015; Iglesias et al. 2009b; Norgall and Wichert 2013; Rosas et al. 2014; Shen et al. 2013). Some of the articles referred systems that enable caregivers to monitor patients at home (Iglesias et al. 2009b). For instance, Hervas et al. (2013) propose a system to manage cardiovascular disease through an end-to-end software application for patients and physicians and a rule-based reasoning engine that combines the monitoring of the blood pressure by means of mobile devices with other clinical parameters.

Fall detection systems were reported by 22 articles (Freitas et al. 2014; Koshmak et al. 2013; Terroso et al. 2013; Ando et al. 2015; Backere et al. 2017; Basili et al. 2016; Cao et al. 2012; De Maso-Gentile et al. 2015; Ejupi et al. 2015; Foroughi et al. 2008; Gschwind et al. 2015a; b; Helmy and Helmy 2015; Jeon et al. 2017; Juang and Wu 2015; Kiselev et al. 2015; Lee et al. 2013; Maglogiannis 2014; Ogonowski et al. 2016; Pierleoni et al. 2015; Rakhman et al. 2014; Zambanini et al. 2010). For instance, Foroughi et al. (2008) proposed a method to detect various posture-based events in a typical older adult monitoring application in a home surveillance scenario; an ambient-based fall detection system based on a pressure-sensing triboelectric nanogenerator array was proposed by Jeon et al. (2017), for appropriate filtering and distinguishing between falls and daily activities; and the use of sensors and smart devices were also reported by Backere et al. (2017). Moreover, the iStoppFalls (Gschwind et al. 2015a) project (i.e. a randomized controlled trial to assess the feasibility of the intervention programme to deliver unsupervised exercises to older peoples in their residential environments) aims to prevent common fall risk factors.

AAL solutions can modify external factors (e.g. environmental factors) to improve the participation of older adults (World Health Organization 2001). In this respect, 30 articles (Bamidis et al. 2010; Barham et al. 2015; Carús et al. 2014; Danilovich et al. 2017; Doyle and Walsh 2015; Eichelberg et al. 2014; Göllner et al. 2011; Holthe and Walderhaug 2010; Iglesias et al. 2009a; Kue et al. 2015; Kuhn et al. 2009; Li et al. 2009; Magar et al. 2017; Martin et al. 2013; McCrindle et al. 2011; Mitseva et al. 2009; Mokhtari and Feki 2007; Núñez-Naveira et al. 2016; Passas et al. 2012; Payyanadan et al. 2017; Pensas et al. 2013; Preuss and Legal 2017; Schaad et al. 2016; Schenk et al. 2011; Seewald et al. 2010; Siegel et al. 2014; Silveira et al. 2013; Sun et al. 2009; Ullah et al. 2012; Wolfgang Inninger and Nicole Wagner 2012) were identified reporting AAL solutions aiming to improve the participation of older adults. In particular, some articles aim to decrease social isolation by promoting interactions with other people. Mitseva et al. (2009) developed a system to guarantee safety at home, to support basic daily activities and to promote daily interaction with relatives, friends and caregivers, giving older adults the feeling of safety and preventing their social isolation. Also, Pensas et al. (2013) presented the AMCOSOP system that might enable older adults to stay connected to their families, friends and safety networks, even if they are living by themselves.

Easy management of the social agenda to improve participation of older adults was another type of AAL system found in this systematic review. For instance, Iglesias et al. (Iglesias et al. 2009a) described a digital agenda application, which was tested by a group of older adults. This customized personal agenda allows older adults to create agenda entries and to view calendar entries and select a particular telephone number without typing any letter or number.

Also, systems to improve mobility were reported. For instance, the project ‘immer Mobil – be always Mobile’ enables senior citizens to use up-to-date and enhanced mobility offers in rural areas in a convenient and easy way (Wolfgang Inninger and Nicole Wagner 2012).

Finally, the control of home appliances in a home automation scenario was proposed by Magar et al. (2017) using GSM to remotely control home appliances connected by a low-cost wireless network.

Concerning the methods used to evaluate AAL solutions, in this study, the approach of Martins et al. was used (Queirós et al. 2013b) that defines three reference phases. The first phase is the conceptual validation, followed by the prototype test and, finally, the pilot test.

Figure 2.7 presents the distribution of articles by the type of evaluation: 150 articles (i.e. approximately 56%) did not refer to any information about evaluation of AAL solution proposed, 56 articles (i.e. approximately 21%) referred to a conceptual validation of AAL solutions, 31 referred to prototype evaluations (i.e. approximately 12%) in controlled environments, and 20 (i.e. approximately 7%) referred to pilot experiences.

The conceptual validation aims to verify if the idea of the AAL solution is sustainable and deserves to be explored. It can be the whole solution or just a technological component. For instance, signal processing and machine learning algorithms

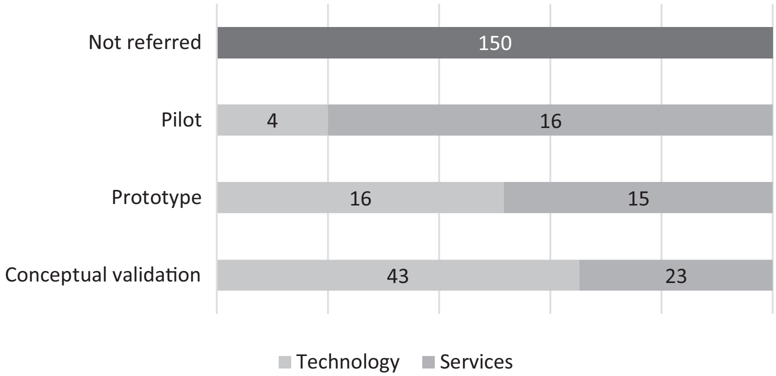


Fig. 2.7 Distribution of articles by type of evaluation

to detect physiological symptoms and infer macro-level activities of the inhabitants was evaluated by comparing the results obtained with this component and real-time data collected in a continuing care retirement community centre (Alam 2017). Also, Vanus et al. (2017) and Pardo et al. (2015) did the same type of evaluation. The first, based on the monitoring of operational and technical functions (unregulated, uncontrolled) in an experimental smart home, trained a neuronal network through the data picked up by the sensors of CO2, T and rH with the aim to indirectly predict CO_2 leading to the elimination of CO_2 sensors from the measurement process. The second study validates an algorithm through a simulation study that uses a Bayesian baseline model to compare with a database of a real application aiming to determine the performance and accuracy.

The prototype test aims to collect information regarding usability and user satisfaction. At this stage there may be a physical implementation of the prototype of the AAL solutions, to be tested by the users. The prototype test is performed in a controlled environment. Oberzaucher et al. (2009), during 14 days, tested a touch screen to interface a video telephone system to evaluate if and to what extent the older adults would benefit from using such a modern multimodal way of communication. Four prototype systems were installed in four private homes and were tested successfully by six persons. It was found that the older adults benefited from the touch-screen control, the proportionally large-scale graphical user interfaces and the video-telephone functions. Also, Fiorini et al. (2017) evaluate the technical feasibility and user acceptability level of a service model for personalized medical support service. The service was tested with 23 older adults (65–86 years) in the DomoCasa Lab (Italy), confirming the ability to utilize these innovative technologies for active and healthy ageing. Usability is often tested in prototype stage. For instance, Kiselev et al. (2015) planned a prototype study to measure usability, user acceptance and effect on physical abilities and quality of life.

Finally, the pilot test aims to evaluate, besides usability, the degree of users' satisfaction and the meaning that a given system or service may have in their lives. The period of tests has a long duration and involves users in their natural context.

The AAL solution developed by Austin et al. (2016) was evaluated for 8 months. This system to measure loneliness by assessing in-home behaviour was tested in a longitudinal study involving 16 older adults who agreed to have the sensor platform installed in their own homes. Also, Holthe and Walderhaug (2010) tested for 1 year the AAL solution they propose. Seven older people and their family carers participated in the pilot trial, which aimed to evaluate the services provided through an individual internet-based digital plan displayed as a calendar page. The video game technology proposed by Gschwind et al. (2015a) to prevent falls was tested with a 148 community-dwelling people, aged 65+ years, and assessment measures included overall physiological fall risk, muscle strength, finger-press reaction time, proprioception, vision, balance and executive functioning. The interventions were delivered as unsupervised exercise programmes in participants' homes for 16 weeks.

2.4 Discussion

AAL emerged as an initiative of the European Union to solve the increasing needs of the older adults, which is one of the major current concerns in terms of sustainability of the modern society (Sánchez-Pi and Molina 2009).

The systematic review demonstrates that the number of articles related to AAL solutions increased during the period 2007–2017, despite the slight decrease in 2017. This can be explained by the fact that the search was performed in the beginning of 2018, and probably there were articles from 2017 still not indexed. The positive development can be related to population ageing and with technological development that facilitates the integration of different components of AAL solutions (World Health Organization 2015).

AAL intends to improve human functioning, autonomy and quality of life of older adults in their natural environments. Therefore, a wide range of solutions is being considered (i.e. the first research question).

Despite that AAL solutions are supported by sensors, which are more reliable in an indoor environment than in an outdoor environment, environment context may be indoor or outdoor, once people have their daily activities inside the house or in the surrounding environments, such as public spaces. Of the retrieved articles, most of them were for indoor environment, namely, solutions for a residential context. Most of the systems were related to indoor activities, as monitoring, fall detection or activity recognition systems, for example, the development of "WhizCarpet," a motion-sensing carpet for tele-monitoring indoor movements and locations, and fall events, with multiple interactive applications, in an unobtrusive way for older adults in the home environment (Chang et al. 2014). This is also related with the number of technological component developments more directed for this indoor context (transform home into a smart home).

Comparing the number of technology and systems with a previous review of 2013 (Queirós et al. 2015), the paradigm has changed: although the number of technological component is bigger than integral solutions, proportionally, the

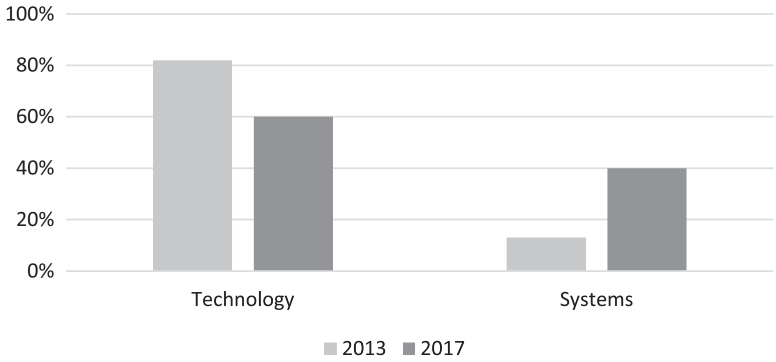


Fig. 2.8 Proportion of number of technological components and systems

number of integral solutions has increased (Fig. 2.8). The development of technological components has decreased compared with the development of systems that can be used by real users. This is in line with objectives of AAL: only systems can be in used in a real context, with real users, and only these AAL solutions can contribute to improve human functioning and guarantee autonomy and quality of life of older adults.

In the previous review (Queirós et al. 2015), less than 5% of the included articles were related to participation of older adults. In this study, this number increased for more than 10%. This is a relevant result considering the main objectives of AAL and turns evident that developers are beginning to be concerned on how technology can be used in the AAL context, instead of looking at specific needs of the users and proposing ways to solve them, for example, falls detection. Despite this result, some articles suggest that even real users prefer solutions to solve health needs (e.g. home monitoring) than social activities that decrease isolation. An example of this are the results of SmartSeniors@home, where the services for general assistance and health, such as audio/video communication, blood pressure monitoring and communication with a health professional, were rated as very attractive compare with services to promote social interaction (Govercin et al. 2016).

Internet protocol television (IPTV) allows interactive and personalized systems and a broad range of interactive possibilities. Older adults know how to use television, and the IPTV protocol could be a way to solve the problem of digital literacy among this population. However, technological advances in terms of interactive services and platforms usually are accompanied complex interfaces as well as their usage, resulting in poor usability. The complexity of IPTV services and content presentations therefore demands novel solutions for IPTV systems to present contents and to allow a more natural and efficient interaction with the users (Ribeiro et al. 2015; Rojc et al. 2017). The results of this review are in line with this concern, since only five of the included articles were related to IPTV solutions.

The integration of AAL is very complex, and there is a need to guarantee interoperability between components to decrease the costs of the implementations and increase efficiency. The interoperability is still a problem (Camarinha-Matos and Afsarmanesh

2011; van den Broek et al. 2010). The results demonstrated that few articles referred concerns about interoperability, which is in line with the study of Dias et al. (2018) where only 2% studies of 2781 referred or explicitly mentioned the issue of interoperability. Common AAL platforms must be based on selected standards to allow interoperability of applications and services (van den Broek et al. 2010).

Considering the second research question (i.e. how are AAL solutions being evaluated?), most of the included article did not refer evaluation processes, which might indicate that the developers still do not give the necessary relevance to this issue. This is in line with the results of Queirós et al. (2015) that report the lack of involvement of real users in all phases of development, and many AAL solutions were only tested in laboratory.

There are many articles referring the use of conceptual validation, especially in technological components or small parts of systems that are tested for the validation of an idea. There is still a high number of this type of evaluation related to systems which may demonstrate that developers are still more concerned to the development and implementation rather than to the evaluation and efficacy of the system developed.

AAL solutions should maintain and increase human functionality through the integration of technology in the natural environment of the older person. The focus should be the person, not the technology, so it is necessary to develop AAL systems that can support users' needs. Considering the relevance of AAL systems to the main objective of AAL, the characterization of AAL systems, found in this systematic review, will be presented in the next chapter.

Annex I: Objective of the Articles Classified as Systems

Authors	Year	Objective	Type of system
Kentta et al. (2007)	2007	To evaluate technology-based service scenarios to support independent living	Safety
Niemela et al. (2007)	2007	To present three scenarios describing how independent living of older adults can be supported with mobile-centric ambient intelligence services	Monitoring
Mokhtari and Feki (2007)	2007	To provide service continuity within the living environment, both indoor and outdoor, by combining technological aids and mobile technologies to facilitate independent living for all in the home or in temporary living environments	Participation
Kaye et al. (2008)	2008	To design and implement a system for application to a community-based clinical trial of the efficacy of a basic sensor net (i.e. motion and contact sensors, RF location systems and personal home computer interaction)	Monitoring

Authors	Year	Objective	Type of system
Foroughi et al. (2008)	2008	To propose a method to detect various posture-based events in a typical monitoring application for a scenario of home surveillance of older adults	Fall detection system
Kuhn et al. (2009)	2009	To promote daily information management for older adults with decreased visual abilities, as well as with limited experience in human computer interfaces	Participation
Iglesias et al. (2009a)	2009	To develop and evaluate a digital agenda application that allows older adults to create agenda entries, to view calendar entries and to access a particular telephone without typing any letter or number	Participation
Iglesias et al. (2009b)	2009	To present a health monitoring system where users can identify themselves by a simple touch device and health information can be wirelessly collected and associated with an identified user	Healthcare
Li et al. (2009)	2009	To introduce an intelligent oven for healthier food choice that is woven inside smart home environments	Participation
Mitseva et al. (2009)	2009	To develop intelligent custom services aiming at improving the quality of life of older adults with pre- and mild dementia living in their own homes and also the quality of life of their caregivers	Participation
Sun et al. (2009)	2009	To build mutual assistance for communities not only allowing efficient utilization of the social resources in maintaining the independent living of older adults but also helping these people maintain their connections to the society and bring them entertainment	Participation
Kaluza (2010)	2010	To present a multi-agent system for the care of older adults living at home on their own, aiming to prolong their independence	Monitoring
Dohr et al. (2010)	2010	To use smart objects and technologies to facilitate home monitoring processes	Monitoring
Coronato et al. (2010)	2010	To present a software infrastructure that enables the rapid prototyping of smart applications for monitoring patients in environments such as homes or hospitals	Monitoring
Zhou (2010)	2010	To propose a personal monitoring system which integrates wearable sensors, 3G mobile phones, smart home technologies and Google Health to facilitate the management of the diabetes disease	Monitoring
Holthe and Walderhaug (2010)	2010	To develop a technical middleware platform with reusable components that enables rapid development of domain-specific applications that can be personalized for individual use	Participation

Authors	Year	Objective	Type of system
Seewald et al. (2010)	2010	To develop applications fostering the social inclusion and well-being of older adults	Participation
Bamidis et al. (2010)	2010	To present an environment offering a flexible combination of personalized care services for general citizens according to their preference or available technologies, as well as a service aiming cognitive and physical training for older adults inside an independent living setting	Participation
Angelo et al. (2010)	2010	To present an internet-based, automated home care ECG upload and prioritization	Monitoring
Junnila et al. (2010)	2010	To present a general-purpose sensor network and a monitoring platform to support applications ranging from older adults monitoring to early homecoming after a hospitalization period	Monitoring
Hidalgo et al. (2011)	2011	To propose a smart process management, based on artificial intelligence planning and scheduling, able to design timed sequences of activities that solve problems in a given environment	Healthcare
Schenk et al. (2011)	2011	To present a system that uses off-the-shelf sensors and telecommunication technologies to measure continuously individual life space and activity	Participation
Alexander et al. (2011)	2011	To present the evolution of an early illness warning system used by an interdisciplinary team composed by clinicians and engineers in an independent living facility.	Monitoring
Boulos et al. (2011)	2011	To present the development of a smartphone application for remote monitoring and management of older patients with multiple chronic conditions	Monitoring
Lee et al. (2011)	2011	To present the development and testing of a home solution for older adults' medication management and communication	Medication
Göllner et al. (2011)	2011	To introduce two design concepts based on mobile technology to help older adults carrying out daily tasks and managing meetings	Participation
Agoulmine et al. (2011)	2011	To present a smart home to help older adults to continue to live an independent life in their own home while being monitored and assisted	Monitoring
McCrindle et al. (2011)	2011	To develop a wearable device that can be used to support older people in their daily activities, to monitor their health status, to detect potential problems, to provide activity reminders and to offer communication and alarm services	Participation

Authors	Year	Objective	Type of system
Losardo et al. (2011)	2011	To identify affordable technologies suitable for contrasting (older adults) depopulation of rural and mountain areas and at fostering their exploitation within the existing framework of social and health services	Monitoring
Hine et al. (2012)	2012	To develop a domestic well-being indicator system to present information to stakeholders and a model-instrumented house to promote understanding among stakeholders regarding home care technology	Monitoring
Fahim et al. (2012)	2012	To develop an android smartphone application to assists older adults for independent living in their own homes	Monitoring
Cao et al. (2012)	2012	To present a fall detection system derived from motion sensors via an android-based smartphone utilizing adaptive threshold algorithms	Fall detection system
Wolfgang Inninger and Nicole Wagner (2012)	2012	To improve the mobility of older adults by matching transportation needs and transportation services	Participation
Passas et al. (2012)	2012	To design and implement a flexible peer-to-peer platform to allow older adults to build virtual communities dynamically based on interests and needs they share	Participation
Ullah et al. (2012)	2012	To present a touch-based smart home controlling system, which augments the older adults' experiences	Participation
Ferreira and Ambrósio (2012)	2012	To present an interoperable health-assistive platform designed to meet the requirements related to caring, monitoring and motivating the older adults in their own environments	Monitoring
Prescher et al. (2012)	2012	To present a home monitoring system aimed at supporting older adults suffering with co-morbidity	Monitoring
Koshmak et al. (2013)	2013	To propose a framework which uses mobile phone technologies together with physiological data monitoring to detect falls	Fall detection system
Pensas et al. (2013)	2013	To design and implement a system that enables the older adults to stay connected with their families, friends and safety network even though they are living by themselves	Participation
Shen et al. (2013)	2013	To propose a videophone system for the care of older adults	Healthcare
Lee et al. (2013)	2013	To design and implement an android-based smartphone with 3-axial accelerometer to support telehealth and detect falls	Fall detection system
Terroso et al. (2013)	2013	To present a system consisting of a wearable sensor unit, a smartphone and a website to detect falls and to notify the family members or stakeholders	Fall detection system

Authors	Year	Objective	Type of system
Silveira et al. (2013)	2013	To propose a system to support active and healthy ageing by providing a proactive training application, running on a tablet, to improve the balance and strength of older adults	Participation
Hervas et al. (2013)	2013	To present a system to estimate the risk of cardiovascular diseases in AAL environments, through reasoning techniques and context awareness	Healthcare
Martin et al. (2013)	2013	To present a system to support daily living activities	Participation
Norgall and Wichert (2013)	2013	To present a universal platform for both AAL and personal health applications	Healthcare
Losardo et al. (2014)	2014	To report an AAL utilization in a real-world context by describing the case of a 92-year-old woman with mild physical and cognitive age-related impairments that was supported by a system to promote her safety and confidence when staying alone at home	Monitoring
Rakhman et al. (2014)	2014	To present a prototype of ubiquitous fall detection and alert system using smartphones	Fall detection system
Siegel et al. (2014)	2014	To study the effects of AAL on quality of life, health and technology acceptance of people at advanced age living in assisted living homes	Participation
Maglogiannis (2014)	2014	To present an application that utilizes a low-cost smart watch together with an android smartphone to allow the transmission, storage and processing of motion data	Fall detection system
Carús et al. (2014)	2014	To present a self-care solution for older adults, based on self-check of health conditions and self-fitness at home	Participation
Rosas et al. (2014)	2014	To create an ecosystem for AAL aiming to facilitate partnership creation between service providers as a strategy to improve care provision and leverage its capacity	Healthcare
Eichelberg et al. (2014)	2014	To present an overview of the architecture and core functions of a technical platform to integrate various assistive systems	Participation
Krishnan and Cook (2014)	2014	To propose and evaluate a sliding window-based approach to perform activity recognition in an online or streaming fashion	Activity recognition system
Suryadevara and Mukhopadhyay (2014)	2014	To present the application of computing technology to determine the wellness of older adults living independently in their home	Monitoring
Stucki and Urwyler (2014)	2014	To propose a passive, web-based, nonintrusive, assistive technology system to recognize and classify activities of daily living	Monitoring
Costa et al. (2014)	2014	To use AAL environments to promote physical activity among older adults	Monitoring

Authors	Year	Objective	Type of system
Freitas et al. (2014)	2014	To present a fall detection system	Fall detection system
Ejupi et al. (2015)	2015	To examine the feasibility of a low-cost and portable Kinect-based system to discriminate between fallers and non-fallers and to investigate whether this system can be used for supervised clinical and supervised and unsupervised in-home fall risk assessments	Fall detection system
Helmy and Helmy (2015)	2015	To present a mobile application for continuous detection of seizures and falls to support people with epilepsy and fall risk	Fall detection system
Ando et al. (2015)	2015	To develop a smartphone-based detector of activities of daily living, able to discriminate between different kinds of falls	Fall detection system
He and Zeadally (2015)	2015	To propose an authentication protocol for AAL systems and to describe how it meets various security requirements	Security
De Maso-Gentile et al. (2015)	2015	To present a low-power free-scale board with a three-axis capacitive accelerometer and a Bluetooth connection to be used in connection with a smartphone for fall detection in AAL applications	Fall detection system
Doyle and Walsh (2015)	2015	To combine different types of technologies to predict changes in well-being and to deliver feedback and interventions to support personal wellness management	Participation
Alemán et al. (2015a)	2015	To present an AmI system that fusions geo-localization sensors data embedded in smartphone devices for the monitoring of older adults	Monitoring
Kiselev et al. (2015)	2015	To evaluate the usability of a motivational interactive training system for fall prevention and stroke rehabilitation	Fall detection system
Richter et al. (2015)	2015	To present an AAL concept related to the care of people suffering from dementia	Monitoring
(Ueda et al. 2015)	2015	To propose a living activity recognition method based on power metres attached to appliances and a positioning sensor attached to the resident	Activity recognition system
Juang and Wu (2015)	2015	To propose an algorithm using the triangular pattern rule to detect fall-down movements of humanoid by the installation of a robot with camera vision at home that will be able to judge the fall-down movements of older adults in real time	Fall detection system
Deen (2015)	2015	To introduce several low-cost, noninvasive, user-friendly sensing and actuating systems	Monitoring
Suryadevara and Mukhopadhyay (2015)	2015	To present the application of computing technology to determine the wellness of the older adults living independently in their home	Monitoring

Authors	Year	Objective	Type of system
Kue et al. (2015)	2015	To present the implementation of a mobile platform that utilizes smartphone hardware such as the accelerometer and voice recording to monitor and react to older adults physical activity and inactivity	Participation
Hill et al. (2015)	2015	To evaluate the feasibility of an attention training application for community-dwelling older adults using mobile technology	Healthcare
Fratu et al. (2015)	2015	To present how a monitoring system fits the Romanian healthcare regulations and procedures requirements for chronic obstructive pulmonary disease and mild dementia patients	Monitoring
Barham et al. (2015)	2015	To present a smartphone application to help older adults to travel independently using public transport	Participation
(Pierleoni et al. 2015)	2015	To propose a method based on the support vector machine technique and implemented on low-cost android smartphones to detect falls of older adults	Fall detection system
Porambage et al. (2015)	2015	To propose a proxy-based authentication and key establishment protocol to safeguard sensitive data generated by resource-constrained devices in IoT-enabled AAL systems	Security
Lee et al. (2015)	2015	To propose a home occupant tracking system that uses smartphones and off-the-shelf smart watches	Monitoring
Chiang and Liang (2015)	2015	To study motion-sensing interaction between patients and systems in various living spaces	Monitoring
Ahanathapillai et al. (2015)	2015	To present assistive technology able to perform activity monitoring, particularly a wrist wearable unit	Monitoring
Ribeiro et al. (2015)	2015	To present the usability evaluation of an application running in a commercial service of internet protocol TV to support home care of older adults	Healthcare
Li et al. (2015)	2015	To investigate the use of emerging sensor technology in a smart home setting to intelligently monitor lifestyle and to detect potential progressive decline in physical and cognitive abilities	Monitoring
Gschwind et al. (2015b)	2015	To compare feasibility and efficacy of two exergame interventions	Fall detection system
Gschwind et al. (2015a)	2015	To assess the feasibility (i.e. exercise adherence, acceptability and safety) of a system able to deliver unsupervised exercise programme in older adults' homes	Fall detection system

Authors	Year	Objective	Type of system
Ogonowski et al. (2016)	2016	To use participative design and persuasive health approaches to allow for seamless integration of a fall prevention system into an older adults' everyday life	Fall detection system
Nakagawa et al. (2016)	2016	To propose a method that uses the acceleration data from wearable devices for classifying activities or events	Activity recognition system
Figueiredo et al. (2016)	2016	To present an emergency application for smartphones, enabling users to simply hit their devices in order to send an alarm signal to an emergency service	Safety
Austin et al. (2016)	2016	To present a system to measure loneliness by assessing in-home behaviour using wireless motion and contact sensors, phone monitors and algorithms developed to assess key behaviours of interest	Monitoring
Chang et al. (2016)	2016	To propose a smart home care system for older adults	Monitoring
Basili et al. (2016)	2016	To propose a fall detection system based on a smartphone and a board with three-axis accelerometer	Fall detection system
Núñez-Naveira et al. (2016)	2016	To evaluate the impact of an e-learning platform on the psychological status of informal caregivers	Participation
Alam et al. (2016)	2016	To present a system able to collect patients' psychiatric symptoms through lightweight biosensors and web-based psychiatric screening scales in a smart home environment and to analyse them through machine learning algorithms to detect psychiatric emergencies	Monitoring
Govercin et al. (2016)	2016	To examine the acceptance of a healthcare system by older adults.	Healthcare
Ciampolini et al. (2016)	2016	To present a strategy for indirect monitoring of health conditions, requiring less participating effort to the older adults	Monitoring
Schaad et al. (2016)	2016	To present a prototype of an intelligent wardrobe	Participation
Damaševičius et al. (2016)	2016	To propose a method for activity recognition and subject identification based on random projections from high-dimensional feature space to low-dimensional projection space, where the classes are separated using the Jaccard distance between probability density functions of projected data	Activity recognition system
Zhou et al. (2016)	2016	To present a system of learning living status by detecting daily activities using finger-worn devices and sharing information to supporters' smartphones	Activity recognition system
Lotfi et al. (2017)	2017	To develop an AAL platform to support both older adults and their carers to overcome the challenges of the care	Monitoring

Authors	Year	Objective	Type of system
Preuss and Legal (2017)	2017	To investigate the introduction of pet robots into domestic settings.	Participation
(Žele et al. 2017)	2017	To design a prototype of a mobile application allowing informal caregivers to monitor daily activities of older adults.	Monitoring
Backere et al. (2017)	2017	To present a risk detection system able to analyse incidents occurring in the home of older adults by using several sensors and smart devices	Fall detection system
Fiorini et al. (2017)	2017	To propose a service model for personalized medical support to provide adequate healthcare service by means of a hybrid robot-cloud approach	Medication
Danilovich et al. (2017)	2017	To present a community-engaged approach to develop a mobile application exercise intervention through focus groups and interviews	Participation
Payyanadan et al. (2017)	2017	To analyse the driving challenges faced by older drivers and guide the development of a customized web-based trip-planning tool	Participation
Jeon et al. (2017)	2017	To propose a cost-effective, fall detection system based on a pressure sensing triboelectric nanogenerator array	Fall detection system
Magar et al. (2017)	2017	To propose home appliances control using GSM	Participation
Spinsante (2017)	2017	To address two case studies in which a smartphone, when equipped with a proper software application, may operate as an inactivity monitor and a drug management assistant	Medication
Miori and Russo (2017)	2017	To develop and create a reference platform by applying technological solutions to simplify the daily activities of older adults and studying how they access dedicated services	Monitoring

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